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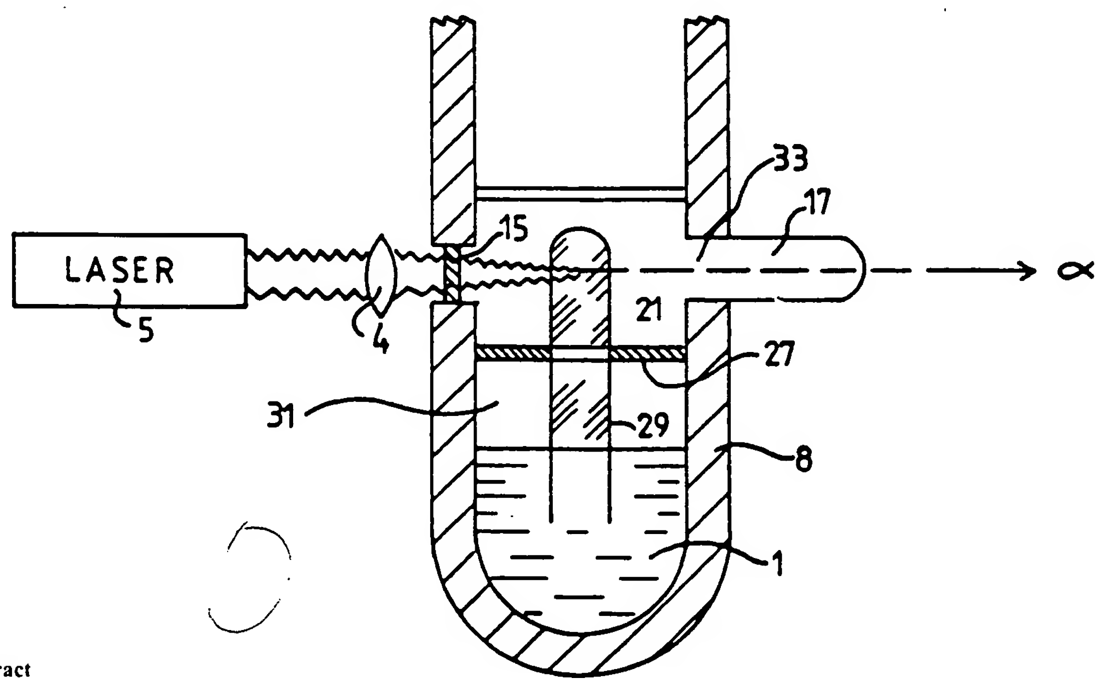
(54) Title: METHOD AND APPARATUS FOR FORMING A COHERENT BEAM OF BOSONS HAVING MASS



(57) Abstract

Coherent light from a pulsed laser (5) is focused by a lens (4) onto a liquid helium film (21) formed by capillary action on bent wire (29) in a vacuum chamber (31). A coherent boson beam is produced by the interaction of the laser light with the liquid helium. The boson beam is extracted through a vacuum transport system (17). A fusion reactor using a coherent boson beam so produced is also disclosed.

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METHOD AND APPARATUS FOR FORMING A COHERENT BEAM OF BOSONS HAVING MASS

BACKGROUND OF THE INVENTION

(i) Field of the Invention

This invention relates to a method and apparatus for forming coherent bosons having mass.

(ii) Prior Art

It is well-known that when intense light from a laser is focused on matter, atoms will absorb energy from photons to become ionized and form a hot plasma. Many works in this field are summarized in the book Plasma and Laser Light, by T. D. Hughes, John Wiley & sons (1976).

It is also that if the light from a laser is powerful enough, say with an intensity greater than 10^{12} watt/cm^2, the atoms will be ionized from the light. Furthermore, the electrons coming out from the atoms will absorb more photons. This is referred to in literature as ATO (= Above Threshod Ionization). See for example P. Kruit et al, Phys. Rev A 15, 1604 (1977): and R. R. Freeman et al. Phys. Rev Let 59 1092 (1987)

The following publications relate to laser cooling for producing an ion beam:

"Possibility of Observing a Condensed Crystalline State in Laser-Cooled Beams of Atomic

Ions, EUROPHYSICS LETTERS, J. P. Schiffer and O. Poulsen, Europhys. Lett., 1 (2), pp. 55-59 (1986).

"Could There be an Ordered Condensed State in Beams of Fully Stripped Heavy Ions?", J. P. Schiffer and P. Kienle, Z. Phys. A. Atoms and nuclei 321, 181 (1985).

According to this invention there is provided a process whereby if the particles in the matter have a density n sufficiently high as to be larger than a critical density n_c and the temperature lower than a critical temperature T_c.

$$n > n_c \qquad (1)$$
$$T < T_c$$

then when intense light from a laser shines on them, bosons will be released upon absorption of the photons, and become a beam of coherent bosons. These bosons may be neutral atoms, ionized atoms, molecules, or nuclei. The mechanism is induced scattering, as outlined in International patent application No. PCT/AU86/00212.

BRIEF SUMMARY OF THE INVENTION

According to the invention there is provided a method for forming coherent bosons having mass comprising causing coherent light to be incident on dense matter.

BRIEF DESCRIPTION OF THE DRAWING

The invention is further described by way of example only with reference to the accompanying

drawing, the single figure of which is a diagram of an apparatus constructed in accordance with the invention.

DETAILED DESCRIPTION

When a system of bosons is under thermal equilibrium, the distribution of their energy obeys Bose-Einstein statistics. If the density of the bosons increases, or the temperature of the bosons decreases, a critical condition is reached and some of the bosons will share the same ground state at the lowest energy and become coherent. This is called Bose-Einstein condensation, and the temperature at which it occurs is the critical temperature. A more thorough discussion concerning Bose-Einstein condensation is given in, for example, the book "Statistical Physics" by L.D. Landau and E.M. Lifshitz, Pergamon Press, 1958, at page 168. Let the critical density be n_c and the critical temperature T_c. We have:

$$n_c = \int_0^\infty \frac{d^3p}{e^{E/kT_c}} \qquad (2)$$

where p, E are respectively the momentum and energy of the bosons, T_c is the critical temperature, and k is the Boltzman constant. Upon evaluation of the integral, they are related by

$$n_c = (2mkT_c)^{3/2}\,\zeta(3/2) \qquad (3)$$

where $\zeta(3/2)=2.612$ is the Riemann function and m is the mass of the charged boson. To evaluate the

numerical values, one can assume a temperature of 10°K and a boson of the order of the mass of the proton, m 1 GeV, and the critical density n_c is $10^{24}/cm^3$. This is at least an order of magnitude higher than the density of most normal matter. Hence, almost all normal matter never reaches this critical condition at this low temperature. Most matter also becomes solid at 10°K, and its density cannot decrease further. The only way to reach the critical temperature or density condition (3) is by lowering the temperature even further.

For liquid helium, the critical temperature is reached at T_c = 2.174°K, at normal atmospheric pressure. The corresponding critical density is of the order of $10^{22}/cm$. Once the critical temperature is reached, some of the helium atoms (He^4), which are bosons, in the liquid state will become coherent and form a superfluid component in the liquid helium. Focusing an intense light from a laser on the superfluid will cause a coherent boson beam to be formed.

Consider the physical process behind the interaction of light with a helium atom. If there is sufficient intensity of light, the helium atom will absorb many photons to become ionized.

$$n_\gamma \gamma + He \rightarrow \alpha + \bar{e} + \bar{e} \qquad (4)$$

Energy requirement dictates that

$$n_\gamma \gamma E \gg E_{He} \qquad (5)$$

where E is the energy of ach individual photon, and E_{He} is the ionization energy of the helium (=27.2eV). If the energy of the photon in the laser is E = 1eV, it requires at least the absorption of 28 photons by an individual helium atom to become ionized. According to quantum electrodynamics the probability of absorbing each additional photon is down by $\alpha \sim \frac{1}{137}$ so that the chance of ionization from ordinary light is extremely small. It requires very intense light from a laser to ionize a helium gas. Once the helium is ionised, the absorption of additional photons is generally done by electrons, and the electrons, and the ionized helium atoms, will become hot.

However, if the helium atoms are coherent as they are in a superfluid liquid helium state, then there is collective interaction among the coherent photons and coherent helium atoms. Then we may have a coherent neutral helium beam in the final state

$$n_\gamma \gamma + n_o H_e \rightarrow n_\gamma \gamma + n_o H_e \quad (6)$$

if the energy of photons is not used up for ionization.

On the other hand, the helium may become ionized and separate into a coherent beam of particles and electrons.

$$n_\gamma \gamma + n_o H_e \rightarrow n_i \alpha + 2n_i (\bar{e} + \bar{e}) \quad (7)$$

where n_γ is the number of coherent photons, n_o is the number of coherent helium atoms, and n_i is the

number of coherent α- particles ($n_i = n_o$). As discussed in patent application PCT/AU86/00212, in the scattering among coherent particles, there is a factor m! increase in probability whenever there is m coherent bosons. So the probability that (6) and (7) occurs instead of (4) has an additional factor like ($n_\gamma! \, n_o! n_i!$). For a 1 Joule light with a pulse of 10 ns from a single mode Nb-YAG laser or an Eximer laser, there are $n_\gamma = 10^{19}$ photons. For superfluid liquid helium, there are about 10^{22} helium atoms in 1 cm^3. For a liquid film of the size 10 mm x 10 mm x 1mm, there are n_o 10^{12} atoms. So, for the scattering of coherent light with superfluid helium, the probability of producing coherent bosons is practically 1, and the scattering can be regarded as a semiclassical scattering.

The critical condition for creation of coherent bosons is discussed in the aforementioned patent application PCT/AU86/00212. More particularly, the ratio "r" is therein defined as:

$$r = \frac{W_c}{W_o} \quad \text{where}$$

W_c = rate of coherent scattering, and
W_o = rate of normal scattering

For production of coherent bosons, the critical condition is $r \geq 1$. That is to say, coherent bosons will be produced if the rate of coherent scattering equals or exceeds the rate of normal scattering.

In the context of the system described in application PCT/AU86/00212, the ratio "r" is there

expressed as:

$$r = \frac{(n_1 + n_2)!}{n_2!}\eta \quad \text{where}$$

n_1 = number of photons,
n_2 = number of coherent particles, and
η = phase space factor.

In the present context, it is convenient to consider the critical condition as being described by the equation for process (6)

$$W_c \simeq Z^{n_\gamma} W_1 \text{, where}$$

W_c is as above defined,
W_1 is the rate of normal scattering, and

$$Z = n_\gamma m^3 \tilde{P}_1 \eta e^{N\varepsilon - 1} \quad \text{where}$$

m = the number of coherent helium atoms,
$\tilde{P}_1$ = possibility of normal photo scattering,
$\eta = \frac{1}{\text{number of final states}}$
e is the exponential number
N = the number of photons per helium atom, and
$\varepsilon = \frac{\omega}{M}$, where

ω = frequency of photons, and
M = mass of helium atom

In this case the critical condition for production of coherent bosons is:

$$Z \geqslant 1.$$

For $n_\gamma = 10^{19}$, $m = 10^{10} \sim 10^{17}$, $N = 10^2 \sim 10^7$, $\varepsilon = 2\text{-}7 \times 10^{-10}$, $N\varepsilon$ is very small

and can be neglected. The critical condition becomes

$$\frac{n_\gamma m^3}{e^2}\tilde{P}_1\,\eta \geqslant 1$$

Insight into this critical condition may be gained by considering the case where $m=m_\gamma$, the number of helium atoms is equal to the number of photons and each helium interact with only one photon. Then eq. (5.19) reduces to

$$n_\gamma \geqslant \left(\frac{1}{e^4\tilde{P}_1\eta}\right)^{\frac{1}{4}} \qquad (5.20)$$

where

$$\tilde{P}_1 = \frac{\sigma_1 T}{4V} \sim 2.0\times 10^{-27}\frac{T}{A}\ cm^2$$

$$\eta = \frac{\pi T}{\omega^2 A} = 1.90\times 10^{-10}\frac{T}{V}\ cm^2 \qquad (5.21)$$

and the γ-He scattering cross section σ_1 is given by Rayleigh theory to be

$$\sigma_1 = \frac{8\pi}{3}\left(\frac{e^2}{m_e c^2}\right)^2\left(\frac{\omega}{\omega_0}\right)^4 \qquad (5.22)$$

at wave length $\lambda=0.488$ μm, or $\omega=2.54$eV; ($\omega_0=13.6$eV). Condition (5.20) becomes

$$n_\gamma \geqslant 1.23\times 10^{10}\left(\frac{V}{T}\right)^{\frac{1}{2}} \qquad (5.23)$$

where the volume V is the square root of the product of normalization volume for helium V_{He} and the volume of laser pulse V_γ

$$V = \sqrt{V_{He} V_\gamma} \tag{5.24}$$

which are given by the experimental condition.

The interaction time T cannot be determined exactly by the above but the smallest value T can take is the period of the light wave. For $V \sim 10^2$cm, T~1μm, the critical condition is $n_\gamma \gg 10^{13}$. If the laser pulse has energy μJ or above, the critical condition will be satisfied.

Generally, while it is not necessary for existence of the critical condition $Z \gg 1$ that the aforementioned critical temperature T_c or critical density n_c prevail it is preferable that such be the case. Particulaly, as above described, for superfluid helium the described Nb-YAG or Eximer lasers provide sufficient energy ($n_\gamma = 10^{19}$ photons) to ensure effective coherent boson production, the superfluid helium being at the critical temperature. In the case where the bosons upon which the coherent light is incident are at a temperature exceeding the critical temperature, the critical condition for coherent boson production may still be met, however, by increasing the number of the incident coherent photons.

The requirements in this respect are, considering the case of production of coherent helium atoms only, ascertainable from the following equation:

$$W_c = \frac{(n_\gamma!)^3\,(m!)^N}{(N!)^{2m}}\left(\tilde{P}_1\ \eta\right)^{n_\gamma - 1} e^{N n_\gamma \varepsilon}\, W_1 \,,$$

where the terms thereof have the meanings described above.

Because of momentum conservation, the produced coherent boson beam will tend to travel along the direction of an incident photon beam. If the average number of photons absorbed by helium is large, the final state will contain coherent He particles. For the above example n $=10^{19}$, n_o 10^{12}, and $E_\gamma =$ 1eV, the energy of individual He particles in the final coherent beam is given by $(n_\gamma E/n_o)\ E_\gamma \sim 10^7$eV.

So, a beam of coherent He particles with energy above MeV is formed. For a 10MeV He particle, the speed is 2×10^{10} cm/sec. The time interval for it to pass through the thickness of the plasma of 1μm is 5×10^{-15} sec. The power contained in the coherent α-beam is:

$$P = \frac{1J}{5 \times 10^{-15}} = 2 \times 10^{14}\ \text{watt} \qquad (8)$$

This is a very substantial concentration of power. Such a powerful beam has many applications including to initiate nuclear fusion in a deuterium pellet under inertia confinement configuration.

The energy of individual coherent bosons produced in the final beam can be adjusted by changing the number of helium atoms of the superfluid component of the liquid helium. The higher the temperature, the lower the component of superfluid, and the higher the energy of the resultant coherent energy beam.

EXAMPLE APPARATUS

The apparatus is illustrated in the drawing as consisting of three major components:

(1) A pulsed laser 5 and its accessories. It may for example be a pulsed Excimer laser like the HE-400-5M or TE-290 series manufactured by Lumonic, 3629 Vista Mercado, Camarillo, CA 93010 USA. Or, it may be a pulsed Nd-YAG laser such as the DCR-3G(1) manufactured by Spectra-Physics, 1250 West Middlefield Road, P.O. Box 7013, Mountain View, CA 94039-7013, USA.

The laser light is focused into a very small spot on a liquid helium film by a lens 4.

(2) Cryostat - A cryostat that can hold liquid helium down to temperature of 1°K or below. Such a cryostat is described in the book by R. J. Donnelly entitled Experimental Superfluidity published by The University of Chicago Press (1967), and can be ordered from Cryo Industries of America, Inc., 24 Keewaydi Drive, Salem NH 03079, USA. Only the internal part of 8 of the cryostat is shown in the drawing, this forming a vacuum chamber 31.

(3) A vacuum chamber 31 inside the cryostat. At the left-handed side in the figure, a window 15 is provided open to allow focussed light from the laser to enter the cryostat. At the right-hand side in the figure, a vacuum transport system 17 is provided leading out of the cryostat, where the coherent boson beam is extracted. In the middle of the chamber is an inverted U-shaped bent wire 29 within which a liquid helium film 21 is formed by, for example, capillary action from a resevoir 23 of liquid helium in the vacuum chamber 31.

The laser emits pulsed light which enters the cryostat through the window slit and shines on the liquid helium film at 1°K~2°K. The helium liquid, in this case superfluid helium liquid, will wet the bent wire from a pool of liquid helium in a reservoir 23 below the wire and within the cryostat 8. To avoid heating the liquid helium directly from laser light, it is advisable to provide insulation 27 between the vacuum chamber that holds the liquid helium film and the liquid helium reservoir below. Further, some means for locally heating the periphery of the interior wall of the vaccuum chamber may be provided at the location between the surface of the liquid helium and the insulation 27, sufficient to slightly heat the wall at that location above the temperature for formation of superfluid helium liquid at that location. On the other side of the vacuum chamber a port 33 leads to the transport system 17. The laser light falls on the liquid helium film and this gives rise to a coherent He particle beam which exits via port 33.

Besides using liquid helium as a target it is also possible to use other materials at temperature below 2°K. The critical temperature will differ from material to material, calculable from the density of material by equation (4). Such material as deuterium will in general be solid at such low temperature. The deuterium is then in a quantum solid state. Because it is solid and not liquid, it does not become superfluid. But, under scattering from coherent light, the coherent deuterium in a quantum solid state will behave similarly as in the case of superfluid helium and become ionized and form a coherent deuterium beam. It is also possible then to generate other boson beams in similar fashion.

The invention may be used for producing energy by nuclear fusion processes involving directing one or more coherent beams of coherent bosons having mass to material capable of undergoing nuclear fusion such as deuterium and/or tritium. In this application the beam formed by the invention may, if necessary, be accelerated by use of conventional accelerators before being so directed. The material against which the beam is directed may, for example, be in the form of pellets, as known, and several beams may be directed simultaneously from different directions.

CLAIMS:

1. The method for producing coherent bosons having mass comprising causing coherent light to be incident on dense matter.

2. The method claimed in claim 1 wherein the dense matter is at low temperature.

3. The method claimed in claim 1 or claim 2 wherein the matter has density greater than a critical density.

4. The method claimed in any one of claims 1 to 3 wherein the matter is liquid helium.

5. The method claimed in claim 4 wherein the liquid helium has superfluid properties whereby the coherent bosons are helium or alpha-particles.

6. The method claimed in any one of claims 1 to 3 wherein the matter is solid deuterium at low temperature.

7. The method claimed in claim 4 wherein said critical density is of the order of $10^{22}/cm^3$.

8. Apparatus for producing coherent bosons having mass comprising means for retaining dense matter, a laser for producing coherent light and means for directing the laser light to the matter to produce the coherent boson.

9. Apparatus as claimed in claim 8 including means for retaining liquid helium for incidence of said coherent light beam thereon.

10. Apparatus as claimed in claim 9 including means for cooling the helium to very low temperatures.

11. A fusion reactor comprising means for retaining dense matter, a laser for producing coherent light and means for directing the laser light to the matter to produce the coherent bosons having mass and means for directing the coherent boson beam to material capable of undergoing nuclear fusion.

12. A method of generating energy by nuclear fusion comprising forming coherent bosons having mass by causing coherent light to be incident on dense matter and directing the coherent bosons to material capable of undergoing nuclear fusion.

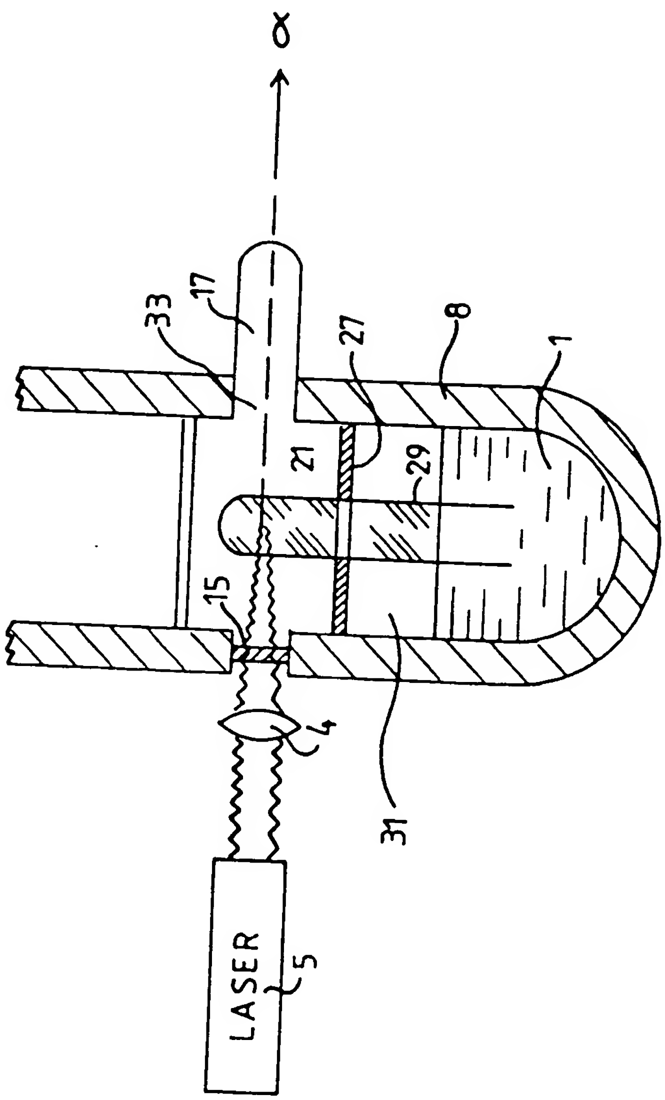

FIG1

INTERNATIONAL SEARCH REPORT

International Application No PCT/AU 88/00411

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.[4] H05H 3/02, 1/24, G21B 1/02

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	H05H 1/00, 1/24, 3/00, 3/02, H01S 4/00, G21B 1/02

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

AU : IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	US,A, 3723703 (EHLERS et al) 27 March 1973 (27.03.73)	(1-3,6,8)
A	DE,A1, 3409478 (LANGE) 31 January 1985 (31.01.85)	
A	WO,A1, 87/00681 (APRICOT SA) 29 January 1987 (29.01.87)	

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
12 January 1989 (12.01.89)	25 JANUARY 1989 (25.01.89)
International Searching Authority	**Signature of Authorized Officer**
Australian Patent Office	F. SPANN

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON
INTERNATIONAL APPLICATION NO. PCT/AU 88/00411

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Members		
US 3723703	DE 2205236	FR 2124573	GB 1333542
WO 87/00681	AU 61947/86	BR 8606780	CN 86105630
	DD 251664	DK 1527/87	EP 232330
	ES 2000736	FI 871300	GB 2191336
	HU 44871	IL 79437	MC 1810
	NO 871238	PL 260805	PT 83069
	ZA 8605567		

END OF ANNEX